

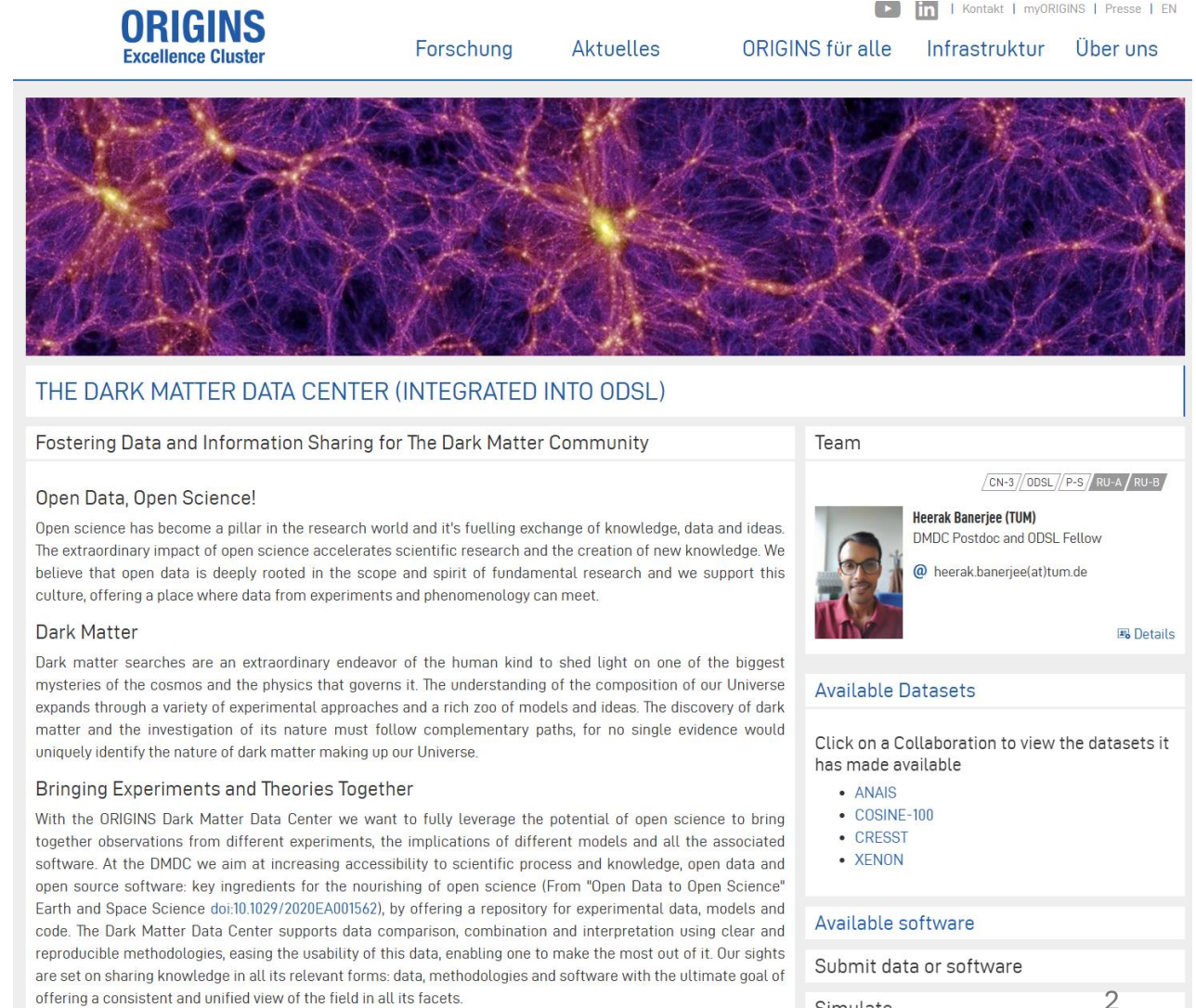
ORIGINS Data Center & Neutrino Oscillation Models

"Democratizing Models" Workshop

Philipp Eller (TUM)

Dark Matter Data Center (DMDC)

- Initiative of the ORIGINS Excellence Cluster in Munich
 - <https://www.origins-cluster.de/odsl/dark-matter-data-center>
 - Funding Period 2019 – 2025
 - The idea is to provide a central place for (direct) DM detection data
 - Open source / open data
 - facilitate and carry out combined analyses
 - Bring together different DM models (theory) and confront those with different data (experiment)



ORIGINS
Excellence Cluster

Forschung Aktuelles ORIGINS für alle Infrastruktur Über uns

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THE DARK MATTER DATA CENTER (INTEGRATED INTO ODSL)

Fostering Data and Information Sharing for The Dark Matter Community

Open Data, Open Science!

Open science has become a pillar in the research world and it's fuelling exchange of knowledge, data and ideas. The extraordinary impact of open science accelerates scientific research and the creation of new knowledge. We believe that open data is deeply rooted in the scope and spirit of fundamental research and we support this culture, offering a place where data from experiments and phenomenology can meet.

Dark Matter


Dark matter searches are an extraordinary endeavor of the human kind to shed light on one of the biggest mysteries of the cosmos and the physics that governs it. The understanding of the composition of our Universe expands through a variety of experimental approaches and a rich zoo of models and ideas. The discovery of dark matter and the investigation of its nature must follow complementary paths, for no single evidence would uniquely identify the nature of dark matter making up our Universe.

Bringing Experiments and Theories Together

With the ORIGINS Dark Matter Data Center we want to fully leverage the potential of open science to bring together observations from different experiments, the implications of different models and all the associated software. At the DMDC we aim at increasing accessibility to scientific process and knowledge, open data and open source software: key ingredients for the nourishing of open science (From "Open Data to Open Science" Earth and Space Science doi:10.1029/2020EA001562), by offering a repository for experimental data, models and code. The Dark Matter Data Center supports data comparison, combination and interpretation using clear and reproducible methodologies, easing the usability of this data, enabling one to make the most out of it. Our sights are set on sharing knowledge in all its relevant forms: data, methodologies and software with the ultimate goal of offering a consistent and unified view of the field in all its facets.

Team

[CN-3](#) / [ODSL](#) / [P-S](#) / [RU-A](#) / [RU-B](#)

 **Heerak Banerjee (TUM)**
DMDC Postdoc and ODSL Fellow
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[Details](#)

Available Datasets

Click on a Collaboration to view the datasets it has made available

- ANAIS
- COSINE-100
- CRESST
- XENON

Available software

Submit data or software

Simulate

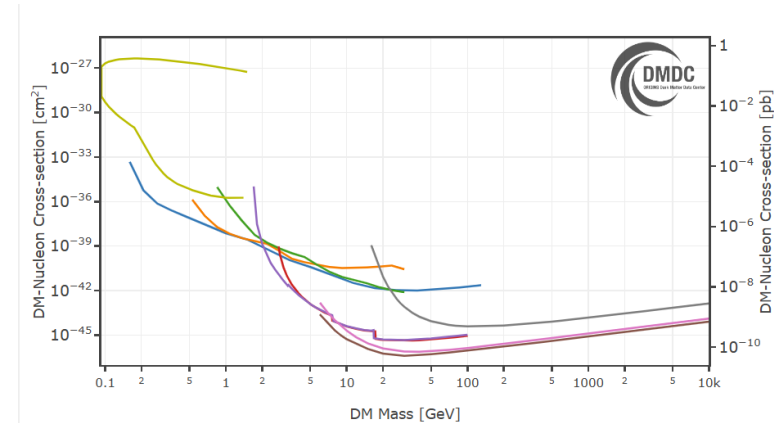
DMDC

- Currently DMDC has datasets from

- ANAIS
- COSINE-100
- CRESST
- XENON

- For some experiments, DMDC provides example notebooks on how to run a fit
- At the moment, DMDC is very person-power limited (1 postdoc, Heerak Baerjee basically *is* the DMDC)

→ No common model / data format exists yet



Interactive
limit plot

ORIGINS 2



- We have submitted the funding proposal for ORIGINS 2
 - Funding Period 2026 – 2032
 - We have put in an extension of the DMDC to become the larger ORIGINS Data Center (ODC)
 - This will expand beyond direct detection DM, and in particular also include neutrino data
 - **Neutrino oscillations** (my expertise), Neutrinoless double beta decay, Neutrino Mass, ...
- No common model / data format exists yet

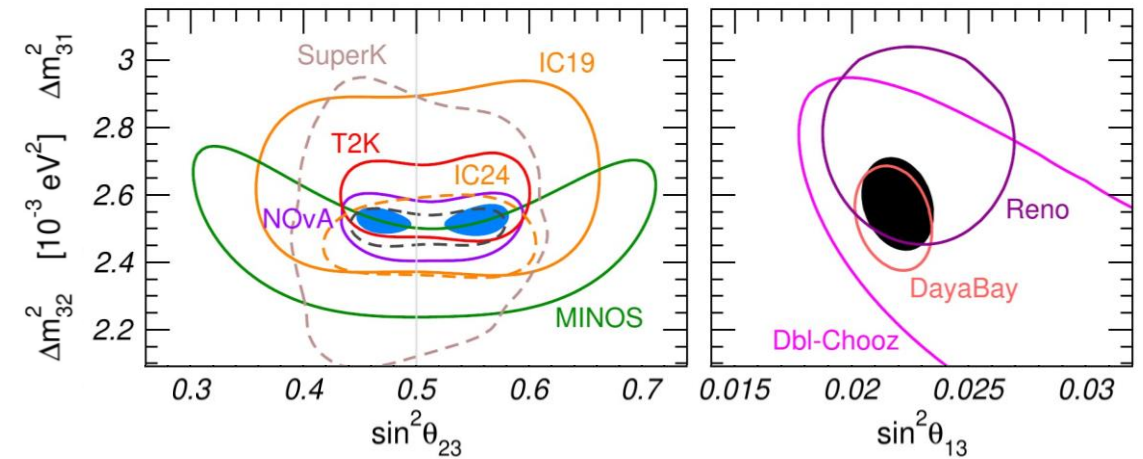
Neutrino Oscillation Data

- Experiments Overview:

- Atm.:
 - Super-K → No public Data
 - IceCube → CSV files + Notebook
 - KM3NeT
- Solar:
 - Borexino → Some data files available, but no oscillation specific ones
 - SNO
 - SuperK → Some text files floating around
- Reactor:
 - KamLAND → Custom text files with data, root file for cov matrix, some tar file with example code
 - SNO+
 - Double Chooz → Custom text files with data on arXiv
 - Reno
 - DayaBay
 - JUNO (future)
- LBL:
 - MINOS → ROOT files from a sterile neutrino analysis on arXiv
 - NOvA → ROOT files with some info, but not detector response
 - T2K → Only chi2 contours available, some actual data release rumored
 - DUNE (future)
 - Hyper-K / T2HK (future)
- ...

Current “Users”

- Global Fitting Group:
 - NuFIT: <http://www.nu-fit.org/>
 - Valencia: <https://globalfit.astroparticles.es/>
 - Bari: Lisi, Capozzi, and others, e.g. <https://arxiv.org/abs/2003.08511>
 - ...
- Groups testing specific (BSM) models:
 - E.g. ourselves:
 - <https://arxiv.org/abs/2407.20388> (PMNS tests with IC-DeepCore, DayaBay, KamLAND, IC-Upgrade, JUNO)
 - <https://arxiv.org/abs/2402.00490> (SM copies with DayaBay, KamLAND, MINOS, NOvA & KATRIN)
- Every group implements their own analysis, that tries to reproduce the official results “reasonably” well. E.g. NuFIT, the perhaps most active global fitting group, they just include norm and shape uncertainties into the analysis until the results kind of match



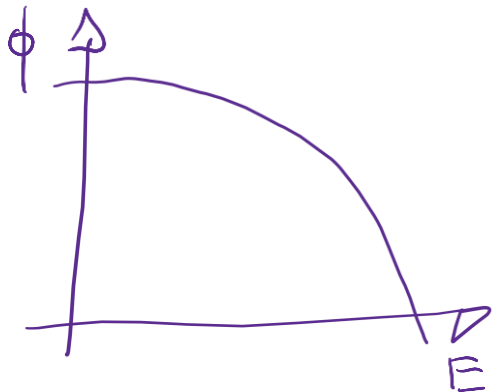
Why Global Fits?

- In neutrino oscillations particularly important:
 - Usually, an experiment can only access one mixing mode (solar vs. atmospheric vs. reactor) (JUNO can do 2 modes)
 - Need multiple experiments to constrain full set of mixing parameters
 - Currently hot topics, such as NMO or CP violation, will almost certainly be answered via global analyses:
 - E.g. T2K + NOvA for CP
 - Or Reactor + Atmospheric for NMO
- However, there is no standard on how to share data and models
 - From experience: I put together the 3y IceCube oscillation data release and was completely on my own, so I just did what I thought was best

Neutrino Oscillation Model

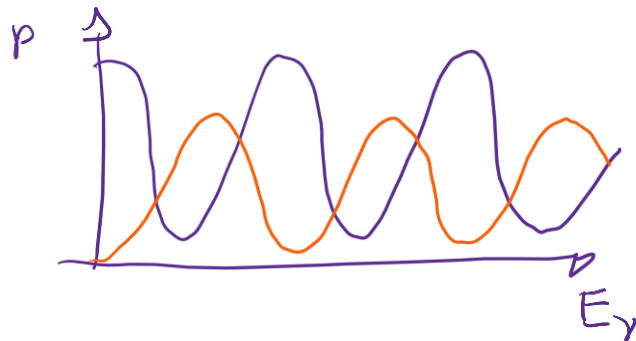
Unoscillated Spectrum

- From Model/Calculation
- From Auxiliary Measurements
- From near detector
- Inclusion of sys. uncertainties



Oscillation Calculation

- Calculation in true neutrino properties (Energy, Baseline, ...) \rightarrow Not accessible
- Either 3-flavour Vacuum Oscillations (easy)
- Or BSM physics
- And/or with Matter effects (usually using external code)



Oscillated Spectrum

- Including Detector effects / acceptance, etc
- Typically realized via MC
- Inclusion of sys. uncertainties



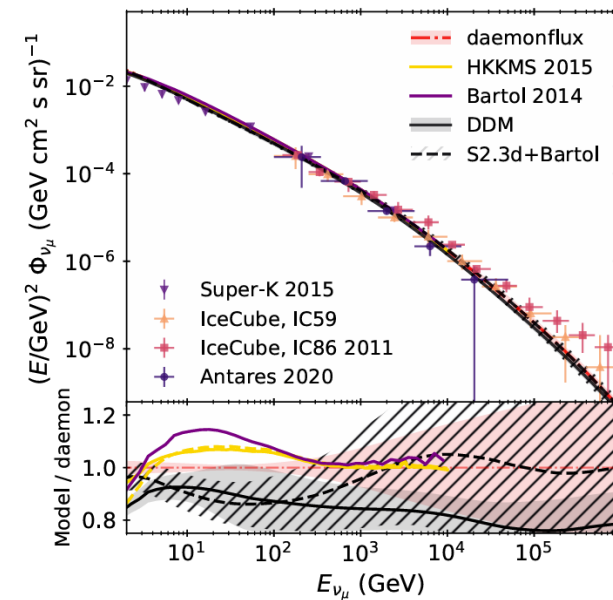
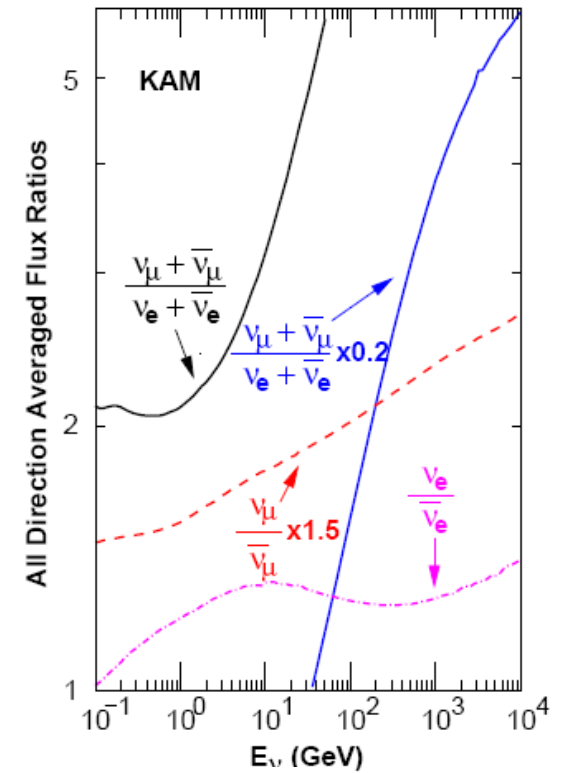
Measured Data

“standard” likelihood

E.g. binned Poisson

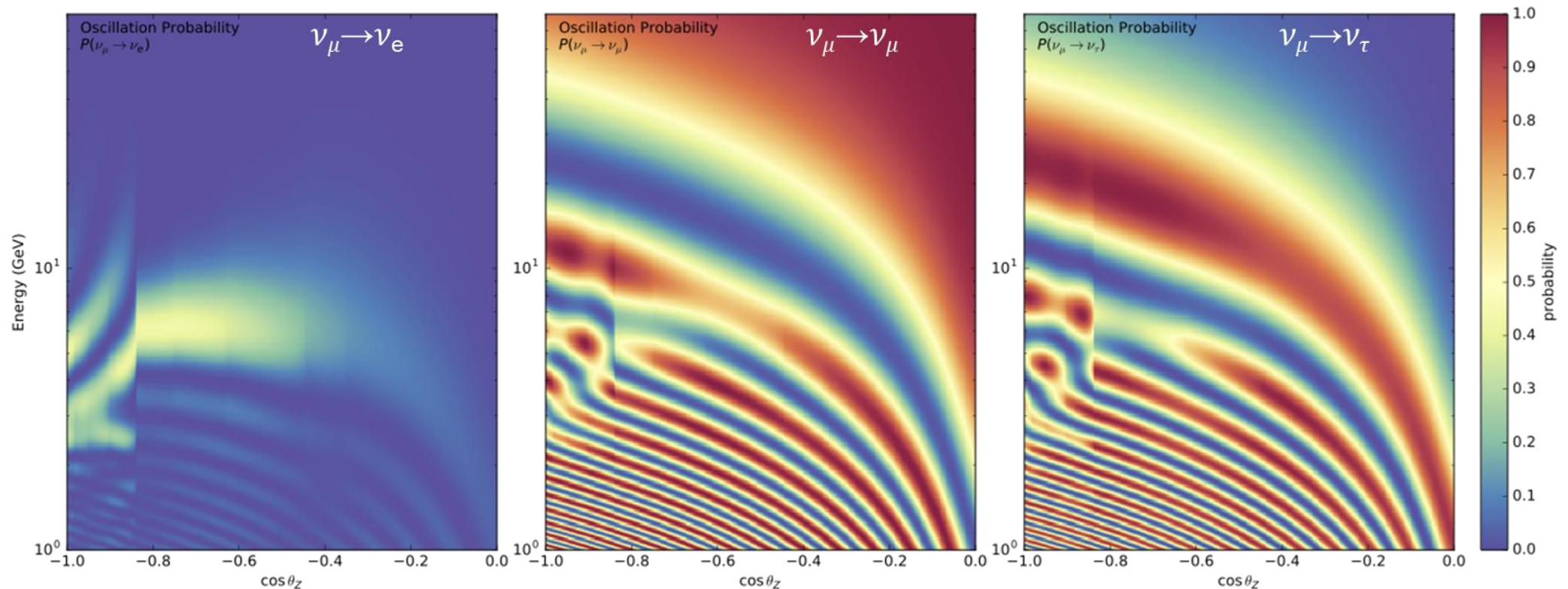
Example: Atm. Flux

- Based on external calculations
 - For example HKKM
 - Tabulated values in 2-3 dimensions
- Or, based on on-the-fly calculations
 - For example MCEq
- Or, data-driven unfolding model
 - E.g. DEAMON flux
- All of those are in truth variables



Oscillations

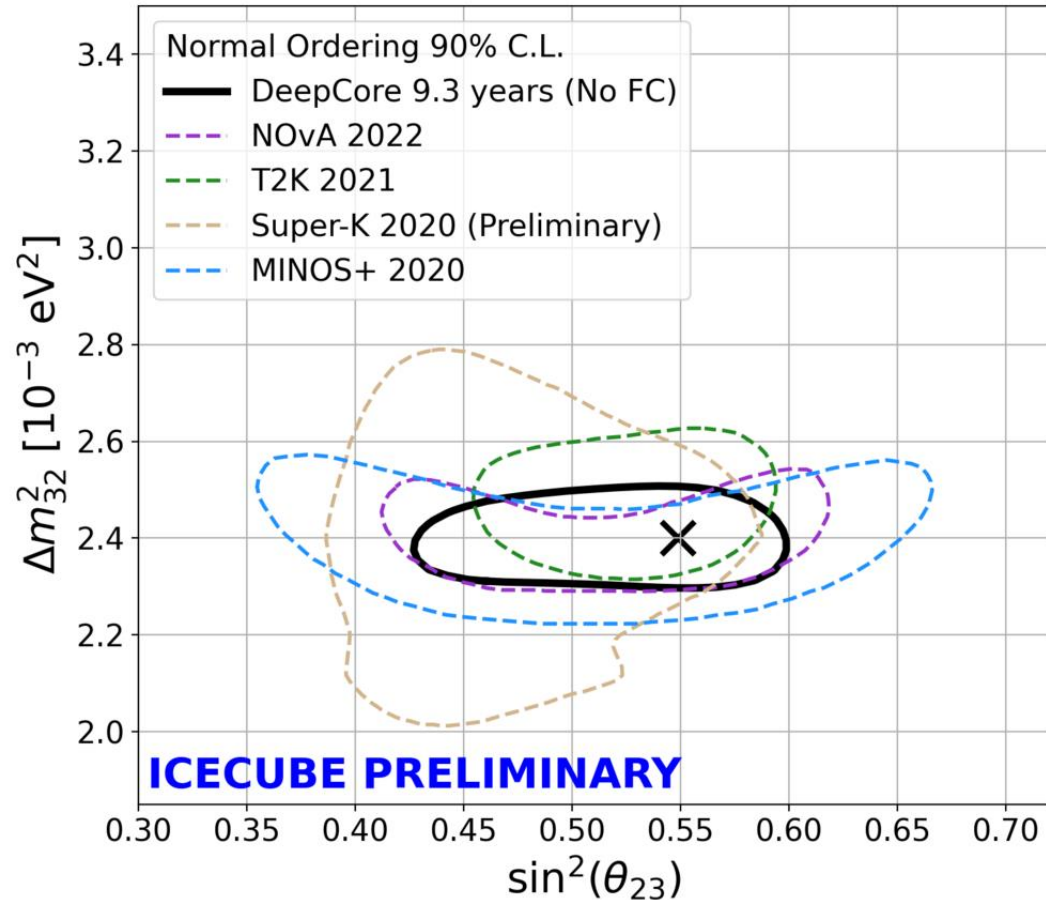
- Example prob3 function + PREM earth profile, ca. 1000 lines of highly optimized code, highly non-linear



Observed Spectrum

- Transfer from truth to observed variables:
 - Either achieved via smearing functions (convolution), for example works rel. well for reactor neutrino experiments
 - Or via transfer kernels obtained via MC: e.g. LBL can be done via fine 2d histograms
- For atmospheric neutrinos, this would become a 5-6d histogram, which is becoming infeasible
- Alternative is to do an event-by-event reweighting of the MC after each change of a (nuisance) parameter

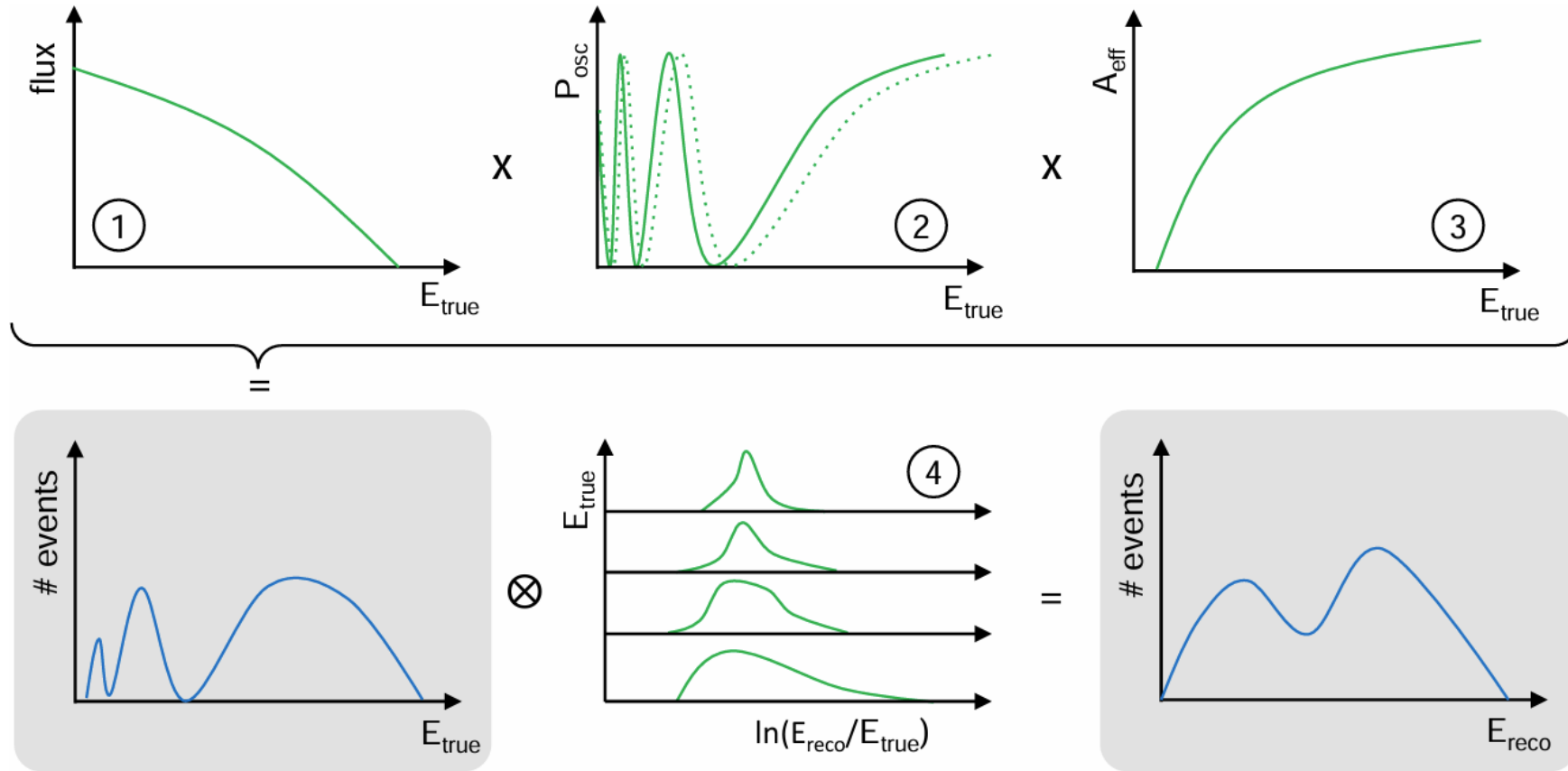
Example Result



- 2 measurement parameters
 - Here 2d C.L. contour
- 20-30 nuisance parameters
- Some parameters may be correlated in global fits with other experiments
 - E.g. Atm. Flux model, Reactor Model, ...

Neutrino Oscillation Model

- Computation of likelihood involves:
 1. Computation of un-oscillated spectrum / flux
 - Should allow for external calculations and correlations across experiments
 2. Evaluation of oscillation probabilities
 - Should allow for external calculations
 3. Transfer from true neutrino properties to observables
 - May require costly MC reweighting / convolution
 4. Vanilla binned Poisson Likelihood
 - Easy



<https://arxiv.org/pdf/1803.05390> “Computational Techniques for the Analysis of Small Signals in High-Statistics Neutrino Oscillation Experiments”

HS³

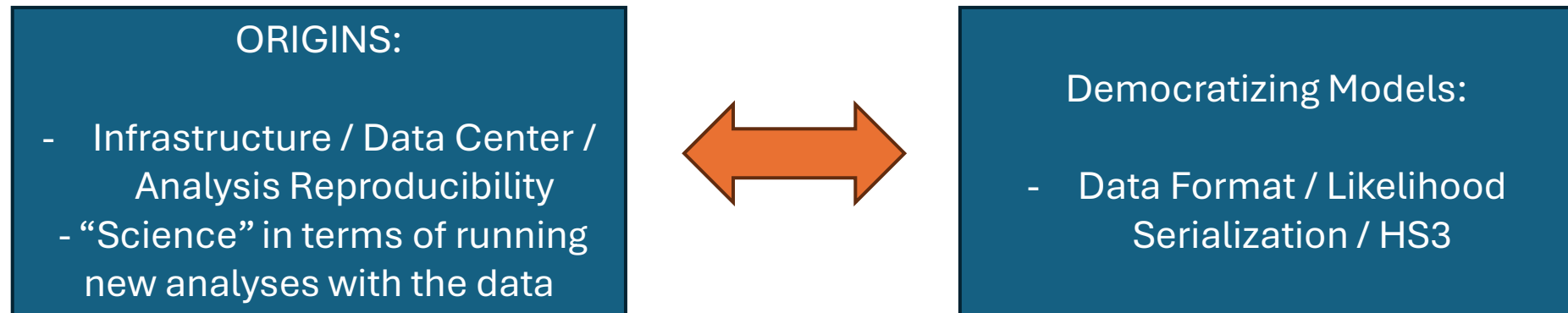
“how well the HS3-like json representation work for your type of the models?”

→ This is a question I don't have a good answer for, but maybe you have...?

My hunch is, that of course it could be used as a data exchange format, but to provide an actual likelihood it would require quite some work.

Summary

- ORIGINS and ORIGINS2
 - Will provide research data infrastructure for DM and neutrino data
 - But neither, DM nor Neutrino, have ANY common way of sharing data or models
 - This is where I would see some potential connection to “Democratizing Models”



- Hosting data / providing platforms could likely be viewed as double funding